Mayo Association

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VIDEO-ROENTGENOGRAPHIC STUDY OF THE HEART AND LUNGS DURING EXPOSURE TO FORWARD ACCELERATION

UNPUBLISHED PRELIMINARY DATA

Apparently the only patho-physiologic effects of forward ($+G_x$) acceleration which pose a practically serious threat to the functional integrity of astronauts during the launch and re-entry phases of space flight arise from the large hydrostatic pressure imbalances which develop in the lungs and thorax.

These pressure imbalances occur in superior and dependent regions in the thorax at the interface (the alveolar membrane) between the alveolar-tracheal-bronchial tree (whose contents (air) have a specific gravity of practically zero) and the pulmonary vascular tree (whose contents (blood) have a specific gravity of about one). Due to this difference in specific gravity, the usual hydrostatic pressure differences which exist at the compartment interfaces in superior and dependent regions of the lungs at 1G are multiplied during exposure to acceleration in direct proportion to the G level involved.

Pressure imbalances also develop in the potential intrapleural space which constitutes the interface between the relatively rigid chest wall and the visco-elastic lung parenchyma which contains these two compartments of widely different densities. The tendency of the fluid contents (air and blood, respectively) of these compartments to redistribute in response to hydrostatic imbalances produced by the changes in weight associated with acceleration is relatively unrestricted and hence results in stresses on the lung parenchyma in proportion to the level of acceleration. These stresses caused by acceleration have been demonstrated

to be capable of causing physical disruption of lung structures of primates including man.

Furthermore, the disproportionate increase in the weight of the blood in relation to the air containing alveoli results in the collapse of these structures in the dependent portions of the lungs and their over distention superiorly. Severe disturbances in ventilation-perfusion ratios develop in these regions of the lungs with absence of ventilation inferiorly so that a pulmonary arterial-venous shunt develops. This shunt is apparently responsible for the severe decreases in oxygen saturation of systemic arterial blood which have been observed under these circumstances.

This project is a portion of a continuing program to elucidate the mechanisms of these effects and if possible to develop technics to minimize them.

The roentgenographic apparatus which was installed in the special centrifuge cockpit in March 1964 in addition to providing dynamic videotape recordings of changes in position of thoracic structures and pulmonary circulation during acceleration, also makes possible the taking of biplane roentgenograms of the thorax.

Figure 1 Roentgenograms of the thorax of a dog supported in the supine position in a molded half-body cast in the centrifuge cockpit when at 1G (left panel) and during exposure

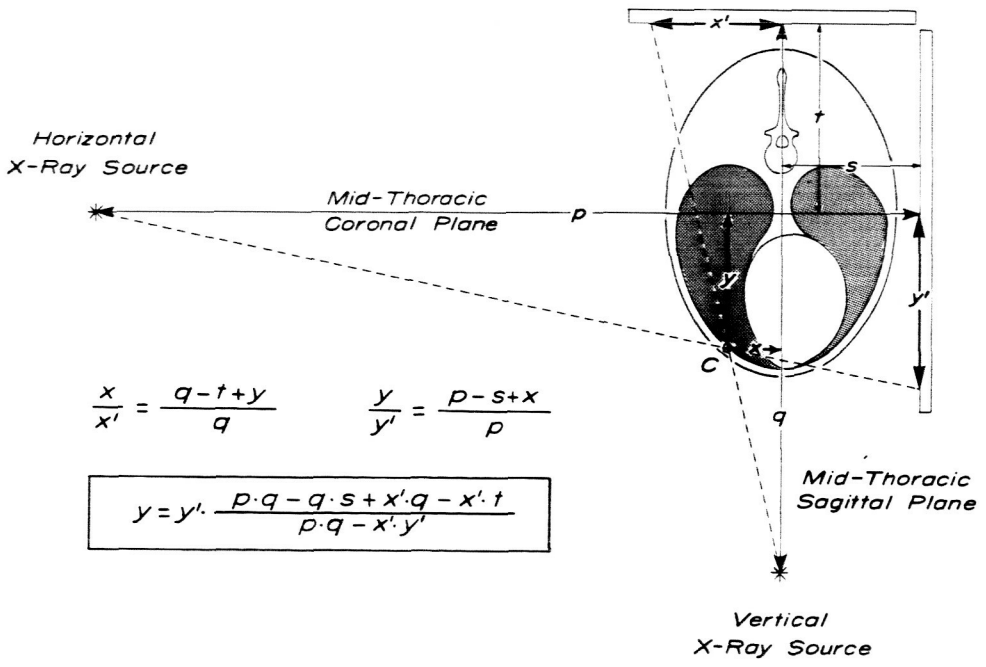
to 7G (right panel). These lateral projections of the thorax in conjunction with a concomitant anterior-posterior projection are used to measure the exact positions of the respective catheter tips in the thorax. The crossed lines which are silhouettes of steel wires on the film cassette surface, juxtaposed to the dog's left side, are used as reference points for these measurements, the horizontal line having been set at the mid-lung coronal plane. M_1 and M_2 indicate the menisci of Ringer's fluid contained in thistle tubes connected in parallel and juxtaposed to the left and right side of the dog, respectively. This hydrostatic system is used to establish the zero reference level of the various manometer-catheter systems by recording this zero reference pressure when the system is opened to the manometers both at 1G and during rotation of the centrifuge. The divergence of the menisci above and below the mid-lung reference line at 7G indicates that the angle of tilt of the cockpit from the vertical of 79 degrees during this exposure was slightly divergent (-3 degrees) from the resultant vector of gravitational and centripetal forces. The arrows are lead strips which mark the point of insertion through the skin of each pleural catheter. V Pl, D Pl, R Pl and L Pl indicate the shafts of catheters inserted into the potential intrapleural space so that their tips rested on ventral, dorsal, right and left surfaces of the lungs, respectively. RA, LA, PA, Ao and Eso indicate catheters with their tips in the right and left atria, pulmonary artery, aorta and esophagus, respectively. Peri indicates a catheter inserted percutaneously into the potential intrapericardial space via a suprasternal approach. The catheter RV whose tip was meant to be in the right ventricular outflow tract had inadvertently advanced into the pulmonary artery when these roentgenograms were taken. Both films were exposed during expiration. At 7G note: (1) the cephalad displacement of the diaphragm, (2) the downward (dorsal) displacement of the heart, (3) the increased radio-lucency of the ventral portion of the thorax presumably due to overdistention of the alveoli and displacement of blood to the dependent regions of the lungs, (4) several of the catheter tips are displace dorsally by more than 2 centimeters during the exposure to 7G, although the displacement of the ventral surface of the thorax of less than 0.5 centimeter is relatively slight. If the shifts in catheter tip positions during the exposure were not corrected, the error in the pressures measured at these catheter tips would be more than 14 cm. of water. The six lead markers mounted on each thistle tube are 1 centimeter apart and those on the esophageal catheters 2 centimeters.

the prone position (as illustrated) or, by rotating the cast so as to rest on the appropriate surfaces of its supports, studies can be made interchangeably in the prone, left decubitus or supine body positions.

For studies in supine, left lateral and prone body positions, the cast can simply be turned so as to rest on the appropriate surfaces of the supports. Catheters were introduced from widely different sites on the skin and advanced to ventral and dorsal pleural sites at heart level.

Since fluid-filled systems were used, correction of measured pressures for the hydrostatic column separating the zero reference plane from the catheter tip is necessary to obtain pressures at the catheter tip. This was done by means of biplane x-rays taken after each change in position, as shown in Figure 4.

CALCULATION OF VERTICAL DISTANCE OF CATHETER TIP FROM MID-THORACIC PLANE BY BIPLANE X-RAYS



$$\frac{x}{x'} = \frac{q-t+y}{q} \qquad \frac{y}{y'} = \frac{p-s+x}{p}$$

$$y = y' \cdot \frac{p \cdot q - q \cdot s + x' \cdot q - x' \cdot t}{p \cdot q - x' \cdot y'}$$

Figure 4 Illustration of method used to determine the position of a catheter tip (C) in the thorax by means of biplane roentgenograms. (Y) is the distance of the catheter tip from the mid-thoracic coronal plane and (X) is the distance from the mid-sagittal plane.

analog-to-digital conversion system for preparation of tapes for analysis by the IBM 1620 digital computer is scheduled for completion by November 1, 1964.

The design specifications for changing the power source of the Mayo Centrifuge to provide 10G capability and to alter the cockpit to provide positive control of its angle of tilt including sinusoidal oscillation through an angle of plus to minus 60 degrees from the resultant has been completed. A request for support for these alterations so as to allow study of the effects of accelerative loads comparable to those which could be encountered during the re-entry phases of space flight, is in preparation.

Earl H. Wood

Earl H. Wood, M.D.
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